Holocene Biogeochemical and Pollen History of a Lake Erie, Ohio, Coastal Wetland[1]

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ABSTRACT. **A five meter sediment core was taken from Old Woman Creek National Estuarine Research Reserve and State Natural Area and Preserve along the western basin of Lake Erie, U.S.A., to determine the historical biogeochemistry of the wetland. Analysis of pollen and sediment chemistry revealed that the area has remained a wetland since ca. 5,500 yr BP, despite changing lake levels. Pollen stratigraphy indicates a distinctive local succession, which has been divided into three zones. Sediments from sometime after glaciation to 5,500 yr BP were characterized by low concentrations of herb pollen; the next zone showed an establishment of hardwood forest vegetation. The modern local vegetation developed after deforestation (about 200 years ago), when sedimentation increased an order of magnitude, phosphorus deposition increased, and the ecosystem changed from a macrophyte dominated wetland to a plankton dominated marsh. After European settlement, the wetland retained its ability to act as a sink and biotic transformer of bioavailable phosphorus; however, abiotic processes seemed to be more important than the biotic transformations that dominated before deforestation.**

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INTRODUCTION

Western Lake Erie is surrounded by a Lake-Plain (remnants of ancient lakes from previous glaciations and glacial retreat) whose gentle slopes are conducive to the formation of wetlands. The area was once known as "the Great Black Swamp"—90% of which was drained after European settlement, mostly for agriculture (Herdendorf 1987). Since wetlands are known for their ability to mitigate floods and retain and detoxify pollutants, it could be surmised that if some of these wetlands had remained intact, they might have reduced cultural eutrophication in the western basin of Lake Erie (Mitsch and Reeder 1992).

The potential of a wetland to act as a sink or transformer of nutrients is tied to hydrology (Gosselink and Turner 1978, Kadlec et al. 1981), spatial and temporal landscape changes (Costanza et al. 1990), and productivity (Brown 1981, Heckman 1986, Whigham et al. 1988, Reeder 1994). Lake Erie wetlands are unique in that their hydrology and formation is dictated by both adjacent lake levels and watershed inputs. How the combined effects of these two hydrologic "forcing functions" would affect nutrient cycling in these ecosystems is not known. One theory is that the wetlands move back and forth with rising and falling lake levels (Herdendorf 1987, Mitsch et al. 1989).

There is a paucity of information on the climatic, vegetational, and water level histories of the Lake Erie Lake-Plain and Till-Plain areas following the end of the Wisconsin Glaciation. Such information would help explain effects of changing climate, lake levels, and watershed deforestation. For example, there is disagreement on the interpretation of recent lake levels from the geologic record. Little data is available to directly determine the fluctuations of recent Lake Erie water levels and their resultant effect on adjacent ecosystems. Coakley and Lewis (1985), and Herdendorf and Bailey (1989) are in agreement as to ancient lake levels but disagree regarding recent history.

The present study explored the historic hydrologic and biogeochemical cycles in Old Woman Creek to assess what changes occurred to the ecosystem as the surrounding hydrology, climate, and landscape changed. Sediment records provide an opportunity to study long-term ecosystem processes such as how wetland landscapes respond to different hydrologic loadings and human impacts (Schoonmaker and Foster 1991). In order to understand the ecosystem from a long-term perspective, a sediment core of post-glacial stratigraphy has been used to approach these questions. The present study used three complementary analyses to reconstruct the ecosystem processes under different climates and human interferences. We combined chemical and pollen analysis with data on past productivity from fossil pigments to reconstruct part of the post-glacial history of Old Woman Creek wetland. This was then compared to recent data on b[illegible]o-chemical processing of phosphorus in the wetlan[illegible]

Site Description and Previous Studies

Old Woman Creek National Estuarine Research [illegible]erve and State Natural Area and Preserve (Old Woman Creek) is one of the last remnants of the pre-European settlement wetlands along western Lake Erie (Fig. 1). This 56 ha wetland lies on the edge of western Lake Erie near Huron, OH, U.S.A. Water depths in the wetland average about 50 cm or less, but this can change dramatically (up to 1 m) throughout the year, not only because of storm pulses from the watershed, but also because of adjacent lake level fluctuations and a barrier beach which may be opened or closed by hydrologic events. Currently, less than 30% of the wetland is covered by the dominant macrophyte, *Nelumbo lutea* (water-lotus). Therefore, unlike most wetland ecosystems, this system is dominated by open

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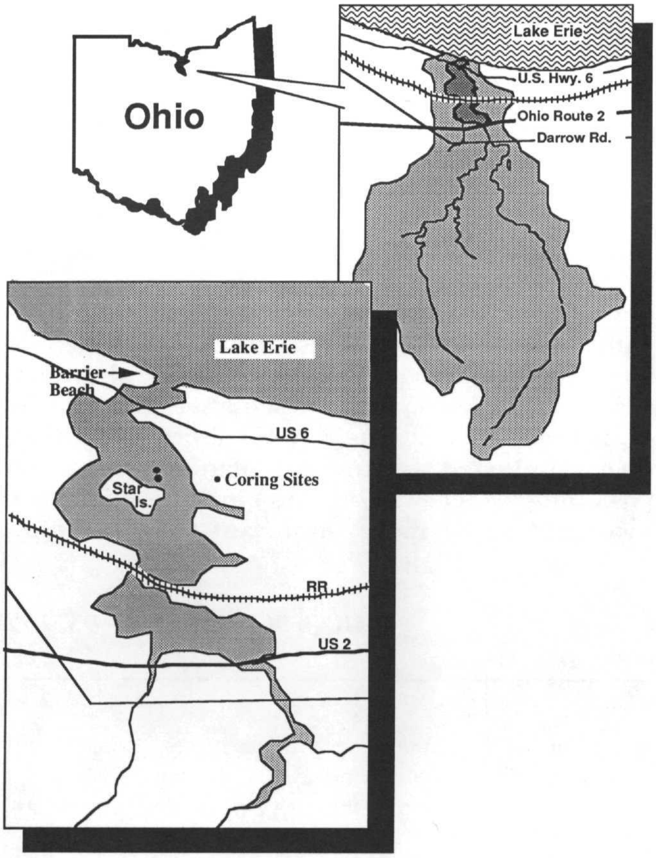

FIGURE 1. Old Woman Creek wetland and its watershed, showing coring sites.

water primary producers rather than macrophytes (despite its shallow conditions). The geologic history of the Old Woman Creek area has been well documented; the most site specific study being done by Herdendorf (1963). The glacial history has been described by Campbell (1955), and the depositional history by Frizado et al. (1986) and Buchanan (1982) who noted a rapid sedimentation rate following deforestation.

The Old Woman Creek study site lies in the deepest portion of the preglacial Huron River Valley (Buchanan 1982). Herdendorf (1992) described Lake Erie coastal wetland formation in terms of the drowning of river mouths. After the Niagara outlet rebounded, the lake rose and stream velocities decreased. This formed the current deposits of alluvium in Old Woman Creek.

A regional history of vegetational changes along climatic gradients for the Lake Erie region is provided in Braun (1961) and Spear and Miller (1976). Buchanan (1982) estimated sediment deposition rates using *Ambrosia* (ragweed) and ^{14}C dates for Old Woman Creek. He found an increase in *Ambrosia* pollen (an indicator of European settlement) with an influx of till-plain and lake-plain sediment. Major studies of pollen and macrofossils in nearby areas include those done at Sunbeam Prairie (Kapp and Gooding 1964), Silver Lake (Ogden 1966), Refugee Road (Garrison 1967), Frains Lake (Kerfoot 1974), Nichols Brook (Calkin and McAndrews 1980), Corry Bog (Karrow et al. 1984), and Bucyrus Bog (Shane 1989). A late glacial and early to mid-Holocene pollen zone stratigraphy for the area south of the Great Lakes was devised by Shane (1987) who analyzed information from previous studies, as well as data from six new sediment cores. Shane noted that there was a warming and drying period after 10,300 yr BP. She also noted, between 8,000 and 4,000 yr BP, a period of further warming and drying characterized by lower lake levels and the establishment of hardwood forest.

MATERIALS AND METHODS

The wetland was cored from the ice using a modified Livingstone piston sampler (Livingstone 1955, Colinvaux 1964). Parallel cores were taken at the site near where a long core was drawn, analyzed, and dated by Buchanan (1982). The first core yielded approximately 2.5 m of sediment, and the second core yielded 5.3 m of sediment. X-radiographs permitted comparison of the depositional patterns of both cores—which seemed to be identical. The longer core (brought up in seven 1-m sections) was the subject of all analyses. Cores were stored wrapped in a least two layers of plastic cling wrap at 4° C.

Pollen subsamples of 0.5 cm^3 were taken at 20 cm intervals along the core (adjacent to sites of chemical analysis), and at 5 cm intervals within the ragweed peak zone. Pollen was extracted using standard acetolysis techniques (Faegri and Iversen 1975) with bromoform separation (Frey 1955). Pollen concentrations were determined by adding a known volume of *Eucalyptus* pollen to each sample (Stockmarr 1971). Identification of pollen was done at 400X and 630X magnification with a light microscope. The pollen sum equaled approximately 300 pollen grains per sample. In those depths with extremely low pollen concentrations, counts were made to less than 100 grains (although up to five times as many *Eucalyptus* grains may have been counted). The percentage diagram is based on the sum of total identified and unknown terrestrial pollen including trees, shrubs and terrestrial herbs. Spores and non-terrestrial plants were excluded from the sum, and *Lycopodium* (clubmoss) spores, *Typha* (cattails), and *Nupar* (water lilly) have been expressed as percentages of the pollen sum. Pollen was counted and diagrams were drawn using a computer program (Eisner and Sprague 1988).

Samples were taken for chemical analysis at 10 cm intervals. Within 72 hours of the cores being opened the sediments were analyzed for sedimentary chlorophyllous degradation products (SCDP). Analysis of SCDP followed the procedure of Sanger and Crowl (1979): SCDPs were extracted from 1 cm^3 samples with 100 ml of 90% acetone, and measuring spectrophotomic absorbances at 660-670 nm peaks in a 1 cm cell. The values are expressed per gram organic matter in SCDP units (Swain 1985).

Percent organic matter was determined by the loss on ignition of an oven-dried 1 cm^3 sample at 550° C (Dean 1974). Measurements of bioavailable phosphorus in Great Lakes tributaries suggest NaOH extractable P is a reasonable estimate of bioavailable P (Logan et al. 1979). Aliquots of dried sediment (0.8 g) were analyzed for bioavailable phosphorus by placing them in 50 ml centrifuge tubes with 40 ml of 0.1 *M* sodium hydroxide (Chang and Jackson 1957), then analyzing for orthophosphate with the ascorbic acid method (Murphy and Riley 1962). Total phosphorus (TP) was determined after digestion with perchloric acid (Sommers and Nelson 1972). Metal concentrations were determined via atomic absorption spectrophotometry. An aqua regia/hydrofluoric acid mixture was used to release metals in Teflon bombs as described by Burnas (1967).

Bulk sediment samples were taken for radiocarbon dating (Table 1). Radiocarbon dating was performed by Beta Analytic Inc. (Coral Gables, FL). Recent dating of the core was obtained from pollen analysis: the *Ambrosia* peak was considered to be a result of deforestation with European settlement. Forest clearance for ship building and agriculture occurred about 180 years ago (Sears 1938), which coincides with ^{14}C dates for a Lake Ontario coastal wetland *Ambrosia* increase dated at 150 ± 50 yr BP by McCarthy and McAndrews (1988).

TABLE

Radiocarbon dates from Old Woman Creek sediment core.

Lab #	Depth (cm)	Material	g. Carbon	C-14 Age yr. BP ± 1 s
27690	201-196	peat	1.2	4,220 ± 20
27692	246-256	silty loam	0.8*	5,040 ± 170
27691	283-303	silty loam	0.5**	8,270 ± 170
27693	374-394	silty loam	0.4*	12,650 ± 280
27694	513-533	silty loam	0.5*	18,750 ± 470

*Sample given quadruple-normal counting time.
**Sample given double-normal counting time.

RESULTS

Physical Properties

Four sediment layers were found in the core. The bottom 280 cm was composed of silty clay and generally contained less than 5% organic matter (Fig. 2). Above this, for about 45 cm, was found a transition zone to peat. The peat zone extended for almost 90 cm, and was always more than 60% organic matter. The peat layer ended abruptly at 117 cm, and was capped by a 4 cm thick layer of uniform pebbles. The top 110 cm of the core was composed of silty loam, and was 5-8% organic material.

Chemical Stratigraphy

Both organic matter and productivity (as evidenced from data on sedimentary chlorophyllous degradation products) were more prevalent in the top of the core (Fig. 2), but there is little correlation between the two (r = 0.27; n = 50). The peak productivity (or the time of maximal preservation of chlorophylls) was at 223 cm. Productivity remained relatively stable (about a three-fold decrease from the initial peak) from 250 cm to the top of the core, with the exception of two peaks (each about a two-fold increase) at 123 cm and 100 cm. The latter increase coincided with a peak in phosphorus, as did the only indication of productivity in the lower portion of the core.

Phosphorus deposition was quite variable. The deposition of bioavailable phosphorus (NaOH-P) decreased to barely detectable levels when productivity (as measured by both organic matter and SCDP) was highest. The concentrations of NaOH-P did not correlate with values for TP (r = 0.16; n = 50), which may suggest biotic processes are important in phosphorus cycling. Iron and manganese concentrations remained fairly stable throughout the core, and increased upwards; although three episodic increases in Mn were found in the lower 2 m.

Pollen Stratigraphy

Pollen zonation was done by qualitative inspection of the pollen percentage diagram (Fig. 3). Gramineae (grass) and Cyperaceae (sedge) pollen were the dominant taxa throughout all zones.

Zone OW-1 (530-280 cm) contained grass and sedge and characterized by hydrophytes, such as *Nymphaea* (water-lily), *Typha* (cat-tail), and *Equisetum* (horsetail). No tree pollen was found in this zone, with the exception of the presence of *Carya* (hickory) pollen in one sample at about 450 cm. Pollen concentrations were usually less than 15,000 grains cm^{-3} in this zone.

Tree pollen, mainly *Quercus* (oak), *Ulmus* (elm), and *Carya* (hickory), was characteristic of Zone OW-2 (280-140 cm), although grass still dominated. Other herbs appeared, notably *Artemisia* (sage) and *Rumex* (sorrel). *Salix* (willow), *Betula* (birch), *Juglans* (walnut), and *Acer* (maple) were all present. *Pinus* (pine) and *Picea* (spruce) pollen were present in small amounts, probably representing long-distance transport. The hydrophytes dropped off toward the middle of zone OW-2. Pollen concentrations were above 90,000 grains cm^{-3} in this zone.

Zone OW-3 (140-0 cm) showed an increase in early successional species, such as willow, *Fraxinus* (ash), and *Tilia* (basswood), as well as concurrently decreased *Quercus*, *Carya*, and *Acer* pollen. *Lycopodium* also declined sharply. The *Ambrosia* peak was at 131 cm. Pollen concentrations decreased in this zone, averaging about 50,000 grains cm^{-3}.

DISCUSSION

Chronology

Since glacial till was not cored, it is presumed that the core represents a later portion of post glacial events. Of the five radiocarbon dates, the bottom three are inconsistent with the glacial history, and the small amounts of organic carbon have probably been contaminated by significant amounts of old carbonates from the watershed. The two dates above 250 cm are more reliable because of the higher percentage of organic carbon. These dates are similar to chronologies established at other sites. The beginning of the disturbance zone (European settlement: OW-3) is determined by the ragweed rise at 131 cm, which has been dated by historical records at ca. 180 yr BP. These dates translate to sedimentation rates of approximately 0.07 cm/yr during the post-glacial, and 0.7 cm/yr after deforestation, which is consistent with the rates calculated by Buchanan (1982) from his Old Woman Creek core. No erosional event, except for the possible scouring of the peat, are discernible from the core. The radiocarbon dates show no inversions.

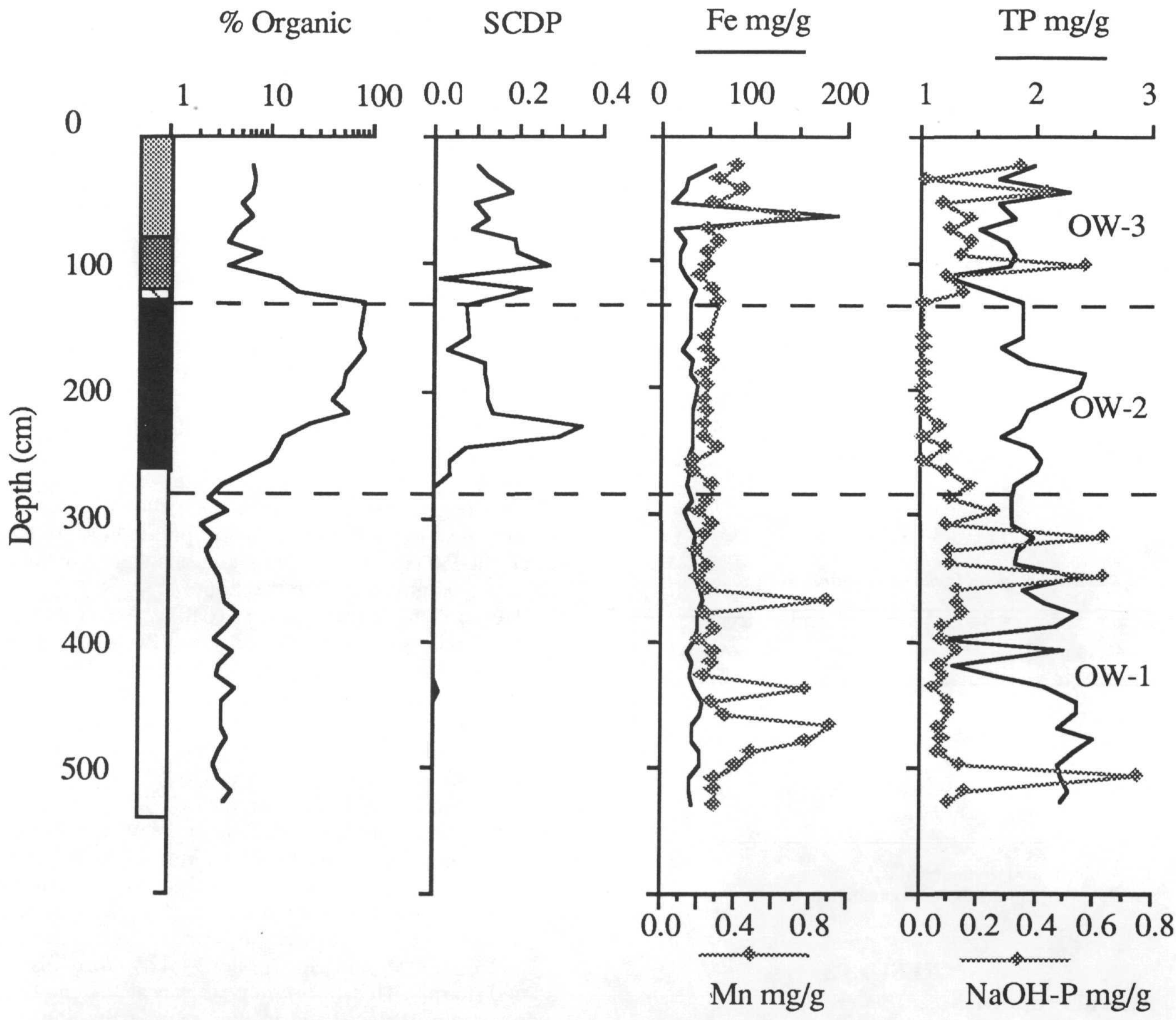

FIGURE 2. Percent organic matter, sedimentary chlorophyllous degradation products (SCDP), and concentrations of nutrients (Mn, Fe, TP, and NaOH-P) in the Old Woman Creek sediment core.

Local Vegetation History

The Old Woman Creek pollen record reflects local vegetation changes in the wetland system from the mid-Holocene to modern times. Zone OW-1 is an early succession phase, dominated by Gramineae, Cyperaceae, and other herbs. The absence of tree pollen in this zone is unusual. Specifically, the absence of *Pinus*, which is present in records from 10,000 to 8,000 yr BP at other sites (Shane 1987) further verifies that our record post-dates the pine decline. Zone I is characterized by aquatic macrophytes, which would be indicative of a shallow lake nearshore zone. Although other studies show widespread populations of deciduous forest south of the Laurentian Great Lakes (Ogden 1966, Shane 1987), the absence of arboreal elements indicates that the woodlands were not in the immediate locality, and local non-arboreal pollen elements drastically overwhelmed tree pollen. Another possibility is that tree pollen preservation was poor (Jacobson and Bradshaw 1981). The surrounding area, which supplied the sediments with all the pollen input, was exclusively marshland vegetation, which appears to have effectively screened out the more distant tree elements.

The first trees to be recorded at the Old Woman Creek site are *Acer*, *Quercus*, *Ulmus*, and *Carya* (Zone OW-2). The forests south of the Great Lakes have been found to be less extensive after the mid-Holocene (between 8,000 and 4,000 yr BP) but still generally characterized by widespread mixed hardwood forests (Jacobson et al. 1987). A major hardwood element of northwestern Ohio, *Fagus* (beech), is absent in this record. This is supported by Braun (1961), who notes that *Fagus* forest was not normally found along the shore of western Lake Erie. The peaks in *Quercus* and *Carya* pollen percentages in the Old Woman Creek record after 4,000 yr BP could reflect the very local establishment of forests. Cyperaceae and *Nymphaea* both decrease during this zone, while *Typha* and *Lycopodium* rise to their highest levels. This may be a replacement which could indicate incipient bog

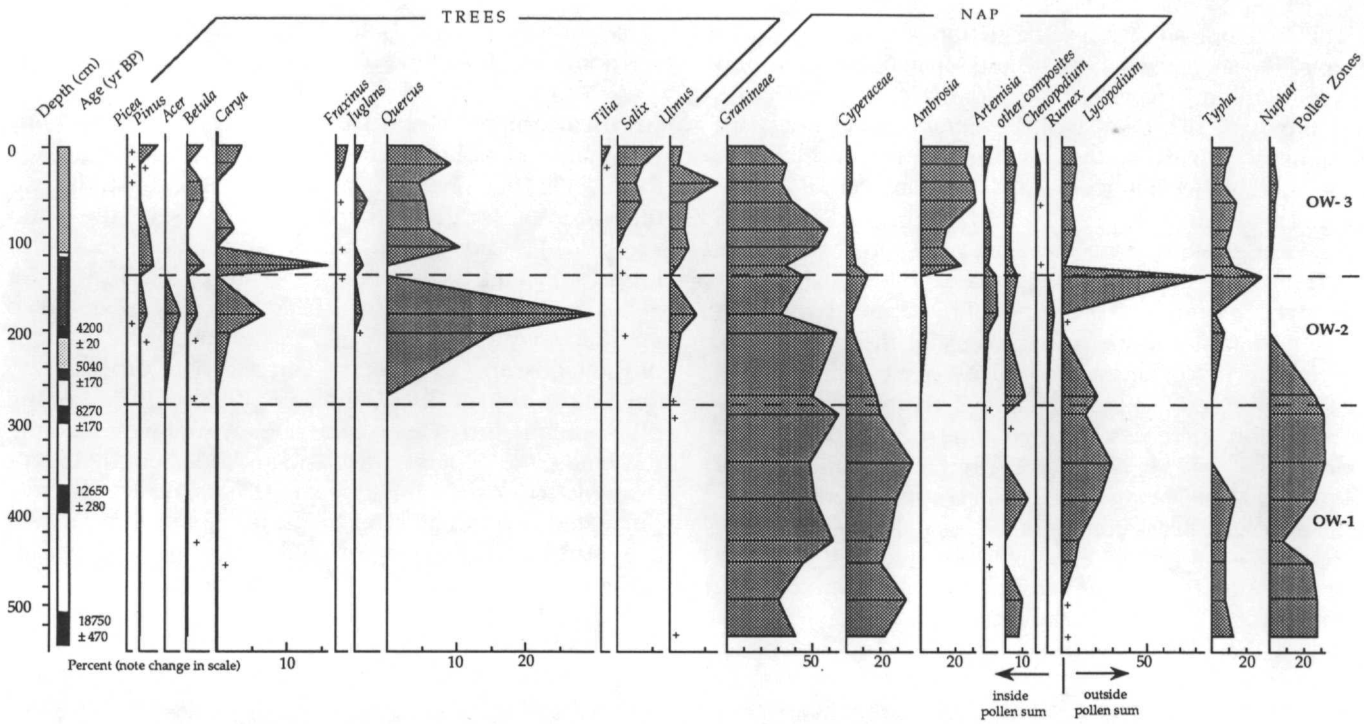

FIGURE 3. Pollen percentage diagram of the Old Woman Creek sediment core. Pollen sum includes all identified, unidentifiable, and unknown grains. Hydrophyte pollen (*Nymphaea* and *Typha*) are not included in the pollen sum but are expressed as percentages of the sum. Note changes in scale.

succession, where the pioneer aquatic phase, signaled by the presence of Cyperaceae and *Nymphaea*, gives way to a graminoid phase of shallower water and some dry land (Dansereau and Segadas-Vianna 1952, Everett 1988). The lower water levels and emergence of more dry areas would allow the establishment of non-aquatic graminoid species (*Artemisia* and *Rumex*), as well as *Lycopodium*.

We believe that either the lake levels were lower than present averages at the time of peat formation or that some barrier must have protected the marsh. Although the peat zone may not be a complete stratigraphy—for example, Everett (1988) shows that the *Scirpus* (sedge) histosols such as the one found in this core should accumulate at about 1 cm y^{-1}—an order of magnitude more than the rate found; however, the lack of any radical changes in the pollen species suggest that no major portions are missing. Alternatively, significant compaction of peat may have occurred; however, soils are not dense enough to suggest compaction. There is modern evidence of peat scouring in nearby marshes. Evidence of possible scouring is supported by the beach zone (uniform pebbles) between zones OW-2 and OW-3. This suggest that the lake edge reached to the cored portion of the marsh.

The disturbance zone (OW-3) shows a general decrease in the major hardwood elements, especially oak and hickory, and a rise in willow, ash, and basswood, which are early successional species and typical of wetter conditions. Deforestation opened the landscape, allowing the establishment of willow, ash, and basswood.

Deforestation also had a drastic effect on marsh structure and function. As marshes and forest upstream were channelized, the velocity of the Old Woman Creek increased with increased flow and intensity. In addition, the soils once held by vegetation in the watershed were now eroding and being carried into the fast flowing waters. The wetland began to silt in as the suspended sediments in incoming waters sank in the low energy waters of the marsh. This resulted in a ten-fold increase in the sedimentation rate. These changes, coupled with rising marsh levels (from both lake level rise and increased inflow) changed the marsh from a sedge dominated system (which accumulates peat) to the modern situation of a standing water marsh dominated by plankton.

The effect of these erosional events on pollen inputs is difficult to measure. No evidence was found of corroded or deteriorated pollen grains, which might indicate redeposition of pollen from eroded soils (cf. Davis et al. 1985). Although erosion as well as streamborne pollen redeposition could account for some of the anomalies in our pollen stratigraphy, the determination of such processes was beyond the scope of the present study.

Biogeochemical History

The post-glacial clays contained little organic matter, and probably represent a lake edge. Slow sedimentation rates, the absence of arboreal pollen, and the presence of hydrophytic vegetation pollen further support this hypothesis. Nutrient deposition is low, and productivity was low. The soil was formed under aerobic conditions.

If Mn deposition rises in respect to Fe depositions, it may indicate mildly reducing conditions (Mackereth 1966, Engstrom and Wright 1984), thus providing a method of determining paleoredox. By inference, mildly reducing conditions should coincide with a release of phosphorus. Fe:Mn relationships showed eras of mildly reducing conditions at about 503 cm, 438 cm, and at 368 cm. These events did not show any correlation with phosphorus events. The increase in both Fe and Mn at 63 cm indicated a zone of migration caused by oxidative conditions in the soil. It may be that the use of Fe:Mn ratios does not work in shallow aquatic systems with short retention times. This could be because the solubilized compounds do not leave the basin, or perhaps reducing conditions are significant enough to release both iron and manganese. We can see no conclusive evidence of biological mediation of the geophysical processes of these metals, and it is unlikely that any Monerans were using these metals as electron acceptors given the paucity of carbon.

The upper part of the core shows that productivity or preservation increases through time (as evidenced by dramatic increases in both carbon and SCDP); and most of the phosphorus being brought into the system is non-bioavailable. The decrease in bioavailable phosphorus during the 4,000 years of peat accumulation suggests the marsh vegetation was transforming bioavailable phosphorus into non-bioavailable forms. Therefore, we conclude that phosphorus entering the wetland was being bound in organic phosphorus compounds resistant to decay. This is consistent with information on phosphorus cycling in productive wetlands (Mitsch and Gosselink 1993). Decay rates were probably low because of anaerobic conditions, although again this is not reflected conclusively in the paleoredox data. However, paleoredox will also not indicate any change if highly reducing conditions were consistently present.

Since deforestation, productivity has remained high, and the deposition rate of phosphorus has greatly increased. As peat formation stopped and sediment and nutrient loads increased, the ability of the marsh to work as a biotic transformer diminished, but its abiotic ability to permanently bury all the phosphorus forms was increased. In fact, on a per year basis much more phosphorus is buried now than when the marsh was forming peat (Mitsch and Reeder 1991). This suggests that shallow water zones with natural hydrology have always been significant in reducing the nutrient load to Lake Erie.

The area retained phosphorus both as a reed marsh and as a plankton-dominated, shallow water wetland, suggesting that either ecotone helped halt the eutrophication of Lake Erie. Although aquatic macrophytes are normally considered to be the major nutrient transformers in wetlands, we did not find that to be the case: as productivity switched from macrophyte dominated to open water dominated, the wetland's ability to act as a significant phosphorus transformer was diminished. This is in agreement with recent field and modeling data suggesting Old Woman Creek plankton may transform up to 8,600 kg P y^{-1} (Mitsch and Reeder 1991, Reeder 1994).

It is probably inaccurate to judge the wetland's ability to transform phosphorus on the basis of SCDP and organic matter deposition. This is because a switch from anaerobic to aerobic sediments would greatly alter the amount of chlorophyllous pigment left in the record (as well as increase decomposition rates). Further, because the system is dominated by plankton, many of the autotrophs in the marsh may be exported from the area by outflowing waters during storms (Klarer and Millie 1992, Mitsch and Reeder 1992). In contrast, when rooted plants are dominant, they tend to decay near where they grew.

Implications for Great Lakes Marsh Succession

It is not possible for us to accurately gauge changes in the level of Lake Erie from this paleoecological study. Part of the reason for this is that the record shows the water levels in the Old Woman Creek area have remained at levels sufficient to encourage growth of shallow water vegetation since >5,500 yr BP. A fallacy perpetrated in many ecology texts is that wetlands are ephemeral portions of the landscape, destined via successional processes to become upland forest (Colinvaux 1993). An interesting phenomenon is that even under heavy sediment loading, this landscape remains a wetland and does not fill in. For example, over the past 25 years, Lake Erie levels have fluctuated more than a meter, yet the area has remained a wetland. Some hydraulic equilibrium must be maintained, since the pollen and stratigraphic record indicates that the site has remained a wetland over even greater time spans and more drastic lake level changes. The steep eroded edges of the marsh indicate that it has existed under higher water levels (probably when drowned further by high Lake Erie levels). This theory is also supported by the Fe:Mn ratios not indicating any reduction during assumed periods of anoxia (based on species assemblages)—differential deposition will only be observed if the Mn is allowed to flow out during mildly reducing periods.

Our data support the observations of Orsen and Howes (1992) who found that wetlands with restricted outflows respond dramatically to abiotic changes; whereas plant communities in marshes more connected with open bodies of water develop from autecological processes. A barrier beach controlling water levels, similar to the one found now, would explain why this system has remained a wetland despite water level changes in Lake Erie that would seem to alter the wetland landscape in the area (Herdendorf 1992, Mitsch et al. 1989). Further support for this theory is the low diversity of aquatic species. Reduced water level fluctuations, such as those produced by a barrier beach, can decrease species diversity in wetlands (Wilcox and Meeker 1991). We suggest that when lake levels are low, the barrier beach expands and remains closed, allowing water to back up into the marsh. Under such conditions the dominant hydrologic force is the inflowing stream. When the lake levels or inflows increase, the barrier beach opens to expel excess water from the wetland.

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